THE INFLUENCE OF THE DURATION AND OF THE RATE OF ARM MOVEMENTS UPON THE JUDGMENT OF THEIR LENGTH

By PROF. J. H. LEUBA, assisted by MISS ETHEL CHAMBERLAIN, Fellow in Psychology, Bryn Mawr College

Description of the Experiments. During the past year I undertook, with the help of the apparatus described in the preceding pages under the name of "An Apparatus for the Study of Kinæsthetic Space Perception", a three-part investigation of the duration and of the velocity factors in the estimation of the length of arm movements made by the forearm. Two of these parts are still unfinished. They deal, one with the source of the constant error arising when a length, objectively limited, is reproduced by a free, *i. e.*, unlimited, movement; the other with the effect of voluntary changes in the velocity with which the reproducing movement is made.

The part here described consists of four series: 1. a Normal Series (N. Ser.)[1]; 2. a Weight Resistance Series (W. R. Ser.)[1]; 3. a Muscle Resistance Series (M. R. Ser.)[1]; 4. a Control Series, or an Increasing Weight Resistance Series (I. W. R. Ser.)[1].

The method used throughout was the modification of the Method of Average Error called the Method of Constant Stimuli. The observer's task in this method is to compare a standard movement with a number of fixed comparison-lengths so chosen that the smallest seems distinctly shorter and the largest clearly larger than the standard (St.)[1], and to express his judgment by one of the words, "smaller", "equal", "greater". I have used only three comparison lengths (C.)[1]. The results show this small number to have been sufficient for our purpose.

In each of the four series, the St. Movement (Mt. in the singular and Mts. in the plural)[1] was a length of 8° gone through in the upward direction and beginning each time at a different point between 0° and 5°. The zero point is the one indicated by the pointer when the arm is held horizontally. The reason for this latitude in the starting point of the St., and for a similar latitude in the starting point of the C. was

[1] These abbreviations will be used throughout the article.

the wish to make judgments by means of the sense of position impossible.

In the N. and in the W. R. Ser., the C. Mts. began between 25° and 30°, *i. e.*, approximately midway between the position of the St. in all Ser. and that of the C. in the M. R. Ser.

In the N. Ser. the Mt. was unimpeded; in the W. R. Ser. a resistance of 1½ kilogr. was provided in the form of a weight attached to a wire running in a groove made in the rim of one of the wheels, the whole being so disposed that the weight was put on only after the St. and before the C. Mt.

In the M. R. Ser., the C. lengths were so placed on the semi-circle as to end at different points within 3° of a point 1° from the extreme position the arm was able to reach. A rest was provided in this series for the back and the head of the subject so that his position with regard to the apparatus would remain constant. A very considerable resistance, due to the pressure of the forearm against the biceps, was thus introduced. It is to be noted that this resistance was not constant from the beginning to the end of the C. Mt., as it was the case in the W. R. Ser., but that it increased steadily until its conclusion.

Two subjects performed the four Ser., one of them (R.), a graduate student in psychology, the other (L.), the writer who was the only subject informed regarding the purpose of the experiment and the detail of procedure. A third subject (H.), a senior student, who had already had a good deal of experience in the comparison of arm Mts., served for the W. R. and the M. R. Ser.

The observers worked with their eyes bandaged, except L. who kept them closed without that help. Practice series were given before each new Ser. and a few tests at the beginning of every session. These sessions were limited to about half an hour's duration, broken by several interruptions for rest.

Introspection was asked for only towards the end of each series.

The directions given to the subjects were simply that they concentrate their attention upon the length of the Mts. and express by the words, "shorter", "equal", and "longer", the relation of the C. to the St. The words "duration" and "velocity" were not mentioned to them, at least not before the introspective account was asked for. They were thus left to move at the speed they liked best.

Results. I. I give first, as a sample, a complete record of the N. Ser. of L. (Table I). The figures indicate, in terms of fiftieths of a second, the duration of the St. and of the C. Mts. when the C. were respectively 7°, 8°.5, and 10° and also the judgment passed by the subject in each case. Observe the

TABLE I

Normal Series

St. = 8° Subject L. Equality judgment 8°.4

C. = 7°						C = 8°.5						C. = 10°.					
—		=		+		—		=		+		—		=		+	
St.	C.	St.	C.	St.	C.	St.	C.	St.	C.	St.	C.	St.	C.	St.	C.	St.	C.
67	85	66	88			73	80	75	84	82	87			83	101	79	93
84	72	83	72			74	58	81	88	80	91			71	97	97	95
63	82	119	68			78	62	81	90	67	88			111	88	73	106
85	57	77	42			63	68	77	76					86	88	88	102
60	65	63	48			79	56	94	77					58	66	112	101
83	67	86	81			73	58	86	93							69	90
60	49					79	77	75	69							82	113
75	54					69	83	75	82							86	109
58	52							95	65							76	94
87	69							85	75							53	94
83	59							76	69							73	102
79	62							47	64							73	101
92	59							55	55							70	64
74	68							63	52							69	74
74	61							60	79							70	80
67	66							106	92							70	85
90	50															74	81
71	43															77	56
88	—															59	78
87	55															71	72
74	46															79	83
																64	94
Sums 1601	1221					588	542	1231	1210							1664	1967
Aver. 76	61					73·5	68	77	76							76	89

Average of all — judgments, St = 75, C = 61, Differ. = — 14.
" " " = " St = 79, C = 76, Differ. = — 3.
" " " + " St = 76, C = 90, Differ. = + 14.

considerable variable error in the duration both of the St. and of the C. In column 7°—, for instance, the St. times vary from 58 to 92. The differences between the compared St. and C. are also considerable. They range in the same column from +19 to —40. Similar variations were found in series of experiments in which the observer was comparing not the lengths of Mts., but the *duration* of pressures upon his fore-finger. I shall use this similarity in a subsequent article to reinforce the thesis that in the estimation of the length of Mts. here dealt with, it is the duration and the velocity, not the length, which are directly perceived. Nevertheless, the average duration of the St., leaving out the columns containing

too few tests, is strikingly uniform: 76 for column 7°—; 77 for column 8°.5=, and 76 for column 10°+. We look upon this uniformity as an indication of the sufficiency of the number of tests taken.

The duration of the individual Mts. varies for L. in this series from a little below one second to a little over two seconds. He moved more rapidly in the M. R. and the I. W. R. Ser.

The most interesting figures of the table are those expressing the duration of the C. When the C. was 8°.5 in length and felt equal to the St., St. and C. were made practically in identical times (77 to 76); when the same C. was felt shorter, its duration was materially less than that of the St. (73.5 to 68). If we pass to the comparison of the St. with a C. length of 10° (felt markedly longer), we find that it took a much longer time to make the C (76 to 89). The proportion existing in this case between the duration of the compared movements is practically equal to that existing between their lengths: $\frac{76+0.5}{90}=\frac{8.5}{10}$ When the C. Mt. was 7°, it was made in considerably less time than the St. (76 and 61). The other columns contain too few tests to yield an average free from the variable time error to which I have drawn attention.

These figures lead, it seems, to the conclusion—a conclusion to be reinforced by our other results—that in comparing, as he thinks, two lengths, L. compares in reality, the duration of two movements made at approximately the same rate. I may add that during the experiment he did not have duration in mind. He strove to reproduce in the C. the sensations of movement experienced in the St. The sensations that drew his attention seemed to be localized in and around the elbow joint.

II. In order to get the duration figures given in Table II, the sums (not the averages) of the —, the =, and the + columns in each series were added, and the total divided by the number of tests included in each column. The differences between the St. and the C. are indicated in parenthesis. The W. R. Ser. of H. includes but 50 tests; of these only ten fall in the + column, hardly a sufficient number for a reliable average. The figure in the equality C. (marked with an asterisk) is not strictly comparable with the others. It is derived from a series not reported in this paper in which the C. Mts. were made considerably higher up on the semi-circle than in the N. Ser. The figure may serve, however, as an approximation.

If the judgments recorded in this table are based, as it appeared probable from the series already examined, upon time

TABLE II

Average duration of all the tests arranged by series and classified according as the C. was judged larger, equal, or smaller than the St.

Subject	Series	— St.	— Diff.	— C.	= St.	= Diff.	= C.	+ St.	+ Diff.	+ C.	Equality C.
L	N	75	(—14)	61	79	(— 3)	76	76	(+14)	90	8°.4
	W R	76	(—10)	66	78	(+ 1)	79	80	(+11)	91	8°.3
	M R	Not enough cases. (6)			48	(— 3)	45	54	(+ 2)	56	7°.3
	I W R	50	(— 1)	49	51	(0)	51	50	(+ 9)	59	7°.9
R	N	39	(+ 2)	41	37	(+ 5)	42	37	(+ 9)	46	8.7
	W R	41	(+ 8)	49	40	(+11)	51	41	(+19)	60	8.5
	M R	32	(+ 6)	38	31	(+ 8)	39	31	(+14)	45	7.5
	I W R	43	(+ 5)	48	40	(+ 7)	47	40	(+13)	53	7.6
H	N										10*
	W R	30	(+ 6)	36	29	(+11)	40	31	(+10) 10 cases.	40	9.8
	M R	29	(+11)	40	29	(+15)	44	31	(+16)	47	7.2

comparisons, we should expect the duration of the compared Mts., in every case in which they are judged of equal length, to bear to each other a fixed relation, whatever be the length of the C. That fixed relation would be one of equality if the subject moved through the C. with the same velocity as through the St. But if he should move systematically slower through one of them, the constant relation could not be one of equality. I assume, of course, in saying this, that the subject is influenced, not only by the duration but also by the speed of his Mts., that, in fact, a quasi-automatic compensation takes place between duration and speed when he is judging of spatial lengths.

The data before us bear out these suppositions. Subject L., moving through the St. and the C. in the N. and in the W. R. Ser. at an approximately equal velocity, finds the C. equal to the St. when both take the same time, shorter than the St. when the C. takes less time, and longer than the St. when it is the reverse. In the M. R. and the I. W. R. Ser., done several days after the others, he again maintains practically the same rate of speed through the St. and the C. Mts., although the absolute speed is considerably increased when compared with that of the first two Ser. Subject R. differs from L. in that she takes the C. more deliberately than the St., and, allowing for the lesser speed of the C. Mts. calls, in the first series, the C. equal to the St. when the former takes her 5 units longer. When it takes her only 2 units longer, she calls it shorter, and

when it lasts 9 units more, she calls it longer. In the W. R. Ser. she proceeds through the C. still more slowly than in the preceding Ser., and the figures show that, even though she is not clearly conscious of it, this decrease is taken into account. Her Equality C. takes her 11 units longer than the St. When the C. takes her only 8 units longer, she calls it shorter, and when it lasts 19 units more than the St., she calls it longer. Her last two Ser. are, in this respect, in full agreement with her first two Ser. The averages from H., as far as they proceed from a sufficiently large number of tests, match those of the two other subjects.

We find, thus, conclusive evidence that these subjects, set to the task of comparing the length of two arc movements, were guided in their judgments by the duration and the rate of the Mts., although their introspection does not indicate any awareness of the fact. The degree of precision with which changes of absolute speed and of relative speed between the St. and C. are taken into account, came to me as a surprise. And the further fact that, making use of duration, the subjects did not try to keep the velocity equal (L. excepted) was, I confess, somewhat disconcerting. I intend to find out at some future time whether persons required to compare the length of two Mts. by means of their duration would not endeavor to move with an equal speed through both.

Explanation. Let us, now, compare in the different series the average lengths of the C. when it was felt equal to the St. of 8°. These lengths are written down in the last vertical column under the head "Equality C." With regard to the influence of the weight resistance, they confirm, in every subject, the results obtained by other experimenters, *i. e.*, the equality C. in the N. and in the W. R. Ser. do not differ materially one from the other. It should not be overlooked that it is the addition of a *constant* resistance which does not alter the length of the Mt. The *increasing* resistance used in the M. R. and in the I. W. R. Ser. produced a substantial overestimation of the C. Mts. But why this overestimation of the C. in the M. R. Ser.? We know from the figures of Table II that it has not its origin in an error of duration: a shorter time is not mistakenly judged equal to a longer one; the lengths 7°.3 and 8° felt equal by L. are made in equal times. If not in the duration, the error must be in the estimation of the rate of Mt. There is as a matter of fact in the M. R. Ser. a gradual reduction in the velocity with which the arm moves through the C. This falling off is correlated with the increasing resistance offered to the Mt. by the forearm pressing against the upper arm. We shall submit figures on

this point in a future paper. But the falling off of the rate is not in itself sufficient to cause an error since, as we have seen, changes in velocity are, under certain conditions, exactly taken into account. It must be that in this Ser. the conditions do not allow of the normal compensatory effect of the speed upon the duration.

At this point we must inquire into the sensory basis for the apprehension of the rate of Mt. The skin sensations,—air pressure and temperature—at best secondary criteria, had been eliminated in the cases of R. and H., by means of a loose fitting glove, reaching almost to the elbow, and overlapped by the sleeve. These sensations being out of the question, there remained those arising from the muscles, from the tendons, and from the joint. When the arm is moved through a fixed number of degrees, the effort made is greater when the velocity is high than when it is low, because a part of the innervation finds its way into the antagonistic muscles, and an increased innervation of the muscles that do the work is required. But I do not see any reason for assuming that, as far as tendinous and muscle sensations are concerned, the untrammelled arm moving upward at a considerable speed yields a sensation-experience different from that produced by a slower movement of the same duration made against a properly chosen resistance. The muscle activity would, it seems, be the same in both cases. The muscle and tendinous sensations cannot, therefore, provide an unequivocal basis for the rate of Mt. One is, thus, driven to the hypothesis that unequivocal speed information comes from the joint surfaces.

What is it, then, that takes place in the joint surfaces when speed changes? Two things: (1), an increase in the pressure of the joint surfaces against each other, corresponding to the greater innervation of the muscles. This pressure-increase produces, presumably, a rise in the intensity of the joint sensations. But an intensity series correlated with an increase in muscular tension cannot, as we have seen, serve as a basis for an apprehension of speed. (2.) Speed-increase means also an increment in the rapidity with which the joint surfaces pass over each other, *i. e.*, an increase, shall I say, in the quantity of the stimulus applied to each one of the joint sense-organs in a unit of time? It is credible enough that a qualitative or a quantitative sensation-difference corresponds to this quantitative increase of the stimulus. We may think of it as being the same sort of difference as the one experienced when the velocity of a wheel, the edge of which rubs against the skin, is altered. Whatever be the psychical effect produced, in the case of the joint organs, by changes in the rate with which the stimuli succeed each other, that seems clearly

the only possible cause of a sensory change corresponding unequivocally to the rate of the Mt.

I shall therefore hold, until further information comes to hand, that our comparative judgments of the length of arm Mts., when the "sense of position" is excluded, is really a comparison of duration and of a peculiar sensory value depending upon the rapidity with which successive joint organs are stimulated. This sensory value may be called the *rate-value* of the joint sensation. That introspection does not clearly reveal the existence of this rate-value is no argument against its effective presence.

We are now prepared to account for the over-estimation of the rate of Mt. in the M. R. Ser, an over-estimation leading to the length errors recorded in Table II. I have said already that as the C. movement proceeds the resistance increases somewhat irregularly and the velocity falls off. It decreases, not for the physiological reason offered by Loeb, but because the effort made at any particular moment to overcome the increased resistance, so as to keep the speed constant, falls short of its purpose, since by the time the effort becomes effective the resistance has again increased. The decrease in speed would not of itself cause the observed error. It is because of complicating circumstances making the correct estimation of the rate impossible that the Mt. is made shorter. What happens is that the rate-value of the joint sensation is obscured by a gradual and somewhat irregular increase in the intensity of the joint sensations,—an increase arising from the increment in muscular tension made necessary by the growing resistance. Furthermore, and chiefly, the necessity of repeated readjustments of the speed to the resistance tends to draw the attention away from the rate-value.

The error is an *overestimation* of the rate because the intended speed is greater than the realized one.

In the W. R. Ser. the disturbing circumstances just mentioned did not exist. There was, indeed, an increase of the muscle tension in the C. Mts., and, presumably, a slight corresponding increment in the intensity of the joint sensations. But this increase was, in this series, constant from the beginning to the end of the C. movement. It did not, therefore, divert the attention from the rate-value and thus no velocity error took place.

If the duration of the Mt. remains undisturbed in the M. R. Ser., it is, I think, because the duration of the Mt. experience as a whole, or of the joint sensations in their entirety, is estimated by means of the duration of other sensations themselves unaffected by the arm movement. It is, therefore, an indifferent matter whether or not any particular qualitative or inten-

sive alteration takes place in any one of the sensory components of the whole Mt. experience. The important points for a correct duration-estimate are that the Mt. should be present in some way in consciousness and that the sensations used to measure its duration—and we know that they are not necessarily the same for every one—remain undisturbed by extraneous factors as long as the Mt. lasts.

In order to verify the preceding explanation of the space error present in the M. R. Ser., a control Ser. was devised. In it the C. Mts. took place over the same portion of the semicircle as in the W. R. and the N. series. A resistance was introduced in such a way that, instead of being constant as in the W. R. Ser., it increased as the C. Mt. proceeded. Thus the pressure of the forearm against the upper arm, and the high degree of contraction of the biceps were eliminated, but the increasing resistance remained. Under these circumstances one would expect, if our explanation is valid, a rate error just as in the M. R. Ser. The resistance provided was a long weight of 2 Kgr. dipping in mercury. During the C. Mt. the weight was gradually lifted out of the mercury. As, according to our practice, the starting point of the C. as well as of the St. varied by a few degrees in this series also, the initial resistance in the C. Mt. varied from 0 to about 300 grams. The amount of resistance at the end of the Mt. was not at all as great as in the M. R. Ser.; nevertheless, the results show, in the case of R., an overestimation of the equality C. practically equal to the one present in the M. R. Ser. (7°.6 against 7°.5 in the M. R. Ser.). The error is not so great in the case of L. (7°.9 against 7°.3 in the M. R. Ser.), yet an unmistakable error in the same direction as in the M. R. Ser. is apparent in his results. It is in fact the size of R.'s error and not that of L. which is surprising in view of the considerably smaller resistance applied in this Control Ser. Lack of time prevented H. from doing this series.

Our account of the over-estimation of the equality C. is thus verified, as far as it was in the power of the Control Series to do.

Historical and Critical. In 1890 J. Loeb published in Vol. 46 of *Pflüger's Archiv*, pp. 1-46, under the title, "Untersuchungen über die Orientirung im Fühlraum der Hand und in Blickraum", certain experiments with arm movements from which he concluded that the more contracted are the active muscles at the beginning of a movement, the greater is the overestimation (p. 41). In order to account for this fact he makes use of two hypotheses, the first of which is superfluous, and the second (dependent upon the innervation theory) is now quite discredited. They are, (1.) the excitability of a muscle decreases as its state of contraction increases; (2.) the

length of a Mt. is judged by the amount of energy sent to the muscles performing it. If, then, we try to make two equal Mts., the second of which follows in the direction of the first and is therefore performed with the muscles in a greater state of contraction, we shall send to the muscles for the execution of the second movement an amount of energy equal to the amount by which the first was produced. But as the more contracted muscles are less excitable than the less contracted ones, an equal amount of energy will produce a shorter length in the second than in the first Mt.

F. Kramer and G. Moskiewicz in "Beiträge zur Lehre von den Lage- und Bewegungsempfindungen" in the *Zeits. f. Psy.*, Vol. XXV (1901), pp. 101-125, repeated Loeb's experiments and, generalizing his conclusions, stated that of two movements intended to be of equal length, everything else remaining equal, the more uncomfortable (*unbequem*) falls short of the other. They rejected Loeb's explanation, and suggested, without putting their supposition to an experimental test, that the ovestimation of the "*unbequem*" Mts. is the outcome of a natural tendency to move more slowly through a difficult Mt. than through an easy one (pp. 121-123). This statement we know to be inexact, unless the effect of an added resistance, as in our W. R. Ser. does not fall within the intended meaning of the word "unbequem".

The assumption of Kramer and Moskiewicz with regard to Loeb's illusion was recently put to a test by Erich Jaensch in "Ueber die Beziehungen von Zeitschätzung und Bewegungsempfindungen", *Zeits. f. Psy.*, Vol. 41 (1906), pp. 257-279. He used for measuring the duration of the Mts. a pencil so constructed that when its point is pressed down upon the paper it recedes into the handle. Air is thus pressed back through a rubber tube into a Marey's tambour. In this way a record is made of the beginning and of the end of the Mts. In one of these two series of experiments the observer, starting with the hand near the chest, moved it away from the body for a certain distance, stopped an instant, and then proceeded in the same direction until he had made a line seemingly equal to the first. In the other set, the direction of the Mts. was reversed, the observer starting away from the body and coming toward it.

His duration records led him to this conclusion: "One may take it as proven that the lengths appear equal because the times used in making them are equal" (pp. 269). He discusses the causes of the lower velocity of the uncomfortable Mts. and comes to the opinion, different from ours, that the chief one is physiological, namely, the decreasing excitability of the contracting muscle.

Loeb's explanation of the decrease in length of the Mt. is

thus taken up by Jaensch as the cause of the decrease in its rapidity. This decreasing excitability hypothesis is shown by our Increasing Weight R. Ser. to be superfluous. Moreover, if the relation it supposes between the degree of contraction and excitability really existed, we would in all likelihood have learned to increase automatically the innervation as the length of the muscle decreases and thus have overcome the tendency to error. Jaensch does not seem to have clearly realized, any more than his predecessors, what our experiments prove, namely, that it is an *increasing resistance* and not an added, constant resistance which causes the velocity error in Loeb's experiments. Neither did he grapple with the real problem, which was to make clear why, while we are usually able to take into account, for the sake of the length of the Mt., minute changes of velocity, under special conditions, a constant error in the estimation of speed takes place. To this problem an answer has been given in the preceding pages.

Introspection revealed that our three subjects made no use of visual imagery. In the case of L. there was at times a vague image of the space covered, but it followed the production of the Mt. and never had the clearness necessary in order to serve as a guide. One of the two subjects we used in other experimental series, and only one, had clear visual images of the length of the Mt. She saw the St. and tried to reproduce an equal visual length. Of all our subjects she was the least accurate. I hope to have the opportunity of finding out whether she also made use of duration and rate in judging of the length of Mts.

In the light of the preceding facts and discussions the complete inadequacy of Külpe's statement is evident: "our judgment of the extent of arm movement is not based (in the author's observation) upon the temporal relations of the movement, but upon the reproduced visual image of the space passed through, and more especially of the extreme positions of the moved arm." (Outlines, p. 348.)

Before closing I must refer to the constant positive error in the Equality C. of the N. and of the W. R. Ser. in the case of the three subjects. (See the last column of Table II.) I have so far neglected it. My reason for doing so is that I have at present nothing decisive to say about it, I do not know how to account for the overestimation of the velocity, that, in my view, it implies. There are several possibilities. I shall probably return to the point in another paper.

Summary of Conclusions. When the sense of position is ex-

cluded, the comparison of the length of arc movements is made through the comparison of the duration of one or several of the sensations arising from the Mts. (preferably the joint sensations) and of a particular value of the joint sensation, called here the rate value.

A quasi-automatic compensatory relation exists between the duration and the rate value.

A gradual increase in the resistance offered to a Mt., whether caused by a weight or by the pressure of the forearm against the upper arm, produces a decrease in the rapidity of the Mt. This decrease, for reasons mentioned above, is underestimated, and thus an overestimation of the length of the movement takes place.

Local signatures cannot be connected with the rate value of joint sensations, for one and the same joint organ is susceptible of a whole range of rate values. It is the joint sensation as a whole, not the rate value, which possesses, or may possess, a local sign.

The comparison of the length of Mts. under the conditions present in our experiments does not necessitate the existence of local signs in the joint sensations. An apprehension of duration and of rate is sufficient.